

## FIRS-2 Remote Sensing from SOFIA

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### ABSTRACT

The FIRS-2 interferometer is a high resolution thermal emission FTS that has operated mostly from balloon, but also has flown in the NASA DC-8. From SOFIA, FIRS-2 could sample the upper troposphere and lower stratosphere for many molecules, most notably water vapor and its isotopes, HDO, H<sub>2</sub><sup>18</sup>O, and H<sub>2</sub><sup>17</sup>O. I will discuss the unique data FIRS-2 could obtain and the instrumental issues that would need to be solved.

### INTRODUCTION

FIRS-2 is a thermal emission Fourier Transform Spectrometer that operates in the far and mid infrared spectral regions (80 to 1500 cm<sup>-1</sup>). It has a high spectral resolution (0.004 cm<sup>-1</sup>) that allows it to resolve discrete spectral lines in the upper stratosphere. FIRS-2 was initially designed to operate from high altitude balloon [Johnson et al., 1998] and has had 12 successful balloon flights over its life time. From balloon platforms, FIRS-2 spectra have been used to obtain concentration profiles for many molecules, including CO<sub>2</sub>, N<sub>2</sub>O, O<sub>3</sub>, H<sub>2</sub>O, HDO, H<sub>2</sub><sup>17</sup>O, H<sub>2</sub><sup>18</sup>O, HF, HCl, HOCl, ClNO<sub>3</sub>, NO<sub>2</sub>, HNO<sub>3</sub>, HNO<sub>4</sub>, N<sub>2</sub>O<sub>5</sub>, OH, HO<sub>2</sub>, H<sub>2</sub>O<sub>2</sub>, HBr, HOBr, OCS, CFC-11, CFC-12, SF<sub>6</sub>, HCFC-22, CCl<sub>4</sub>, and Acetone. The signal to noise of the spectral signatures depends on the strength of the transitions, the atmospheric concentration along the observational line of sight, and the instrument response at the corresponding frequency. Currently, the best instrument response is in the long wavelength end of the spectra, although we hope this will improve in the future with new optics to be installed.



**Fig. 1:** photo of FIRS-2 on a balloon gondola

Above is a photo of FIRS-2 mounted on the floor of a balloon gondola early in the mounting procedure. In this configuration, the light from the sky is brought in by a balanced telescope that would not be used on an airplane like SOFIA. The instrument takes up a space of roughly 6'x6' and weighs on the order of 600 lbs.

### **FIRS-2 on the DC-8**

During AASE-II in 1991 and 1992, FIRS-2 operated on the NASA DC-8 for a total of about 18 flights over mostly the northern hemisphere winter. The DC-8 flew at altitudes ranging from 33000 to 41000 ft during each leg. During these flights, FIRS-2 was observing at zenith angles ranging from 60 to 90 degrees throughout the flights. This was done with the hopes of using the observations at various slant paths to infer concentration profile information. Unfortunately, the signal/noise was not sufficient to obtain profile information. However, we were able to obtain excellent column amounts throughout the flights for a number of molecules. These data were presented in three papers that were part of AASE-II special issues [Traub et al., 1994a; 1994b; 1995]. These papers focused on atmospheric subsidence, photochemical change, and data intercomparison with solar occultation spectrometers.

There are a number of potential reasons the signal to noise from those DC-8 flights weren't sufficient for profile information. The list of possible problems include:

- Vibrations of the aircraft coupling to the optics, especially the beam splitter,
- Vibrations of the aircraft coupling to the detectors,
- Vibrations of the aircraft affecting the sampling laser fringing,
- Modulation of background signal from turbulence in front of viewing optics (see below).
- Sampling rate used to increase spatial resolution was too fast.

One can see from this list that most of the issues had to do with poor decoupling of the instrument from the aircraft vibrations. We believe that we can overcome all of these issues. This will be outlined to some extent below.

### **Science from FIRS-2 on SOFIA**

There are a number of scientific questions we think we could address with FIRS-2 on SOFIA.

- H<sub>2</sub>O and its isotopes in the upper troposphere and lower stratosphere.
- Acetone and H<sub>2</sub>O<sub>2</sub> in the upper troposphere.
- Different observational schemes to give good local concentrations of certain molecules.
- Satellite validation.
- Overhead column and potential partial profiles for a number of tracers and reactive molecules.
- Improved latitude and time coverage of mesospheric O<sup>3</sup>P.
- Spectroscopy of characterized clouds in the thermal infrared (useful for TES).

There are a number of possible observing strategies that can be used to obtain concentrations of water vapor and its isotopes. Probably the best way would be for the line of sight to alternate between a small angle below and above the horizon. The difference between the columns along the line of sight is the path from the aircraft to the tangent altitude of the negative looking angle and back to the aircraft altitude. This method will only get concentrations just below the aircraft. To get concentrations above the aircraft, we will need to make observations at a number of zenith altitudes and leverage the difference in column along the line of sight in a few designated layers to infer profile information. This would work best when operating in the lowermost stratosphere for H<sub>2</sub>O. We have been obtaining H<sub>2</sub>O, HDO, H<sub>2</sub><sup>17</sup>O, and H<sub>2</sub><sup>18</sup>O from balloon observations for a number of years now [Johnson et al 2002a; 2002b]. For our last 2 balloon flights, we have extended the observations into the upper troposphere. From this data, we are confident we could use aircraft observations to retrieve H<sub>2</sub>O isotopes. It would be scientifically

interesting to obtain these observations at a number of latitudes and seasons, especially the tropics. I understand that during the early years of SOFIA most of the flight legs will be only in the northern hemisphere, but this will allow us to get a good baseline before more southerly flights occur.

Our recent balloon observations have been used to obtain useful retrievals of  $\text{H}_2\text{O}_2$  and acetone in the upper troposphere, to an altitude of about 11 km. As a result, these should also be retrievable from an aircraft operating at altitudes in the upper troposphere and lower stratosphere without much difficulty. The observation strategies would be similar to that of  $\text{H}_2\text{O}$  and isotopes.

For molecules that are primarily stratospheric in nature, like HF, HCl, and  $\text{ClNO}_2$ , getting clean altitude information will be difficult because there is little leverage gained by using varying lines of sight. For these molecules overhead columns will be obtainable. Molecules that fall off in the stratosphere like  $\text{N}_2\text{O}$  and the CFCs, some altitude information could be obtained by using varying observation angles. The strategy getting local concentrations using angles just above and below the horizon would also work well for these molecules. The molecules  $\text{O}_3$  and  $\text{HNO}_3$  provide a unique challenge. Both have very strong spectral signatures that may allow altitude information to be obtained using either of the above mentioned observational strategies. This will require further investigation to determine the best way to observe these species.

We recently submitted a paper showing the long term observations of  $\text{O}^3\text{P}$  columns in the mesosphere and compared them to model calculations [Mlynarczyk et al., 2004]. These aircraft observations would allow us to extend our observations to many more times and latitudes than afforded by our balloon observations. Plus, we might be able to make observations during peaks in solar activity which would provide interesting validations for models.

We hope to have FIRS-2 as part of the validation campaigns for EOS Aura from balloon platforms. We would be able to validate retrievals of almost all molecules from all 4 Aura instruments with this one instrument. We believe that we could continue providing useful validation data from a platform like SOFIA. The molecules retrieved by Aura that we would get useful information from FIRS-2 would be  $\text{CO}_2$ ,  $\text{N}_2\text{O}$ ,  $\text{O}_3$ ,  $\text{H}_2\text{O}$ ,  $\text{HDO}$ ,  $\text{H}_2^{17}\text{O}$ ,  $\text{H}_2^{18}\text{O}$ , HF, HCl, HOCl,  $\text{ClNO}_2$ ,  $\text{NO}_2$ ,  $\text{HNO}_3$ ,  $\text{HNO}_4$ ,  $\text{N}_2\text{O}_5$ ,  $\text{H}_2\text{O}_2$ , OCS, CFC-11, CFC-12, SF<sub>6</sub>, and HCFC-22. We would not be able to get OH and  $\text{HO}_2$  from SOFIA unless it was at altitude during daylight hours.

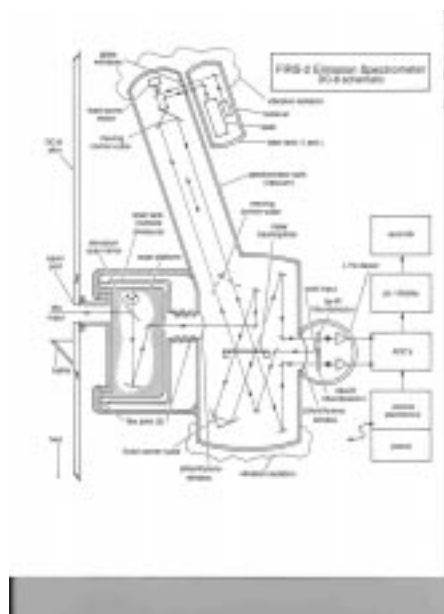
Some of our spectra taken during our last balloon flight showed evidence of clouds along our line of sight. This would most certainly happen often on SOFIA as well, especially during ascent and descent. Such data may be useful for the spectral characterization of clouds throughout the entire thermal band of the atmosphere. The high resolution of the spectra is useful for separating the effects of  $\text{H}_2\text{O}$  and that of the clouds. This would be most useful if there were other instruments on board that could characterize the clouds using different wavelength regions.

### Mounting FIRS-2 on the SOFIA

We would probably mount FIRS-2 in SOFIA in a similar fashion to how we did on the DC-8. In fact, we still have the mounting chassis that we used during that exercise in storage. A schematic of the basic layout of FIRS-2 when on the DC-8 is shown below. We fixed a frame mount to the chair rails of the floor of the plane that had 4 air ride pads on them. FIRS-2 was mounted in a cradle that rode on top of the 4 pads. The pointing optics were also attached to the cradle so they could float with the spectrometer.

There are no suitable window materials in the far infrared spectral region that could be used as a window on the DC-8. As a result, the window of the aircraft was also removed and replaced with a box

inside the aircraft that had an opening to the outside would. The pointing optics resided inside this box. The arms that supported the optics went into the box through flexible bellows to keep vibrations from coupling to the spectrometer. Unfortunately, one of these bellows was somewhat compressed and most likely was transmitting some vibrations. Also inside the box were 2 blackbodies for absolute calibration. These need to be in the box so that there is no difference in the background between the sky view and the blackbody view. One blackbody was cooled by a thermo-electric cooler and the other was heated by the heat sink for the same cooler. This gave a temperature spread of around 40 K when the plane wasn't flying and around 25 K when the plane was flying. The turbulence in the box mitigated the temperature spread. We had an airfoil in front of the box to decrease the turbulence, but this only partially worked. We could hear significant whistling in the box when we opened the door for the sky view. We would want to work on a different design for this if FIRS-2 flew on SOFIA.



**Fig. 2:** Schematic diagram of FIRS-2 when mounted on the DC-8.

The high angle window design of SOFIA would require us to design a different window box than used on the DC-8. This may allow us to have more flexibility in our viewing geometries.

We would need to rethink our method of isolating the instrument from the aircraft. We would certainly like to know the methods used for the SOFIA telescope and see if we could borrow some of those ideas. We also have a few ideas for stabilizing certain optics in our spectrometer to keep them from being susceptible to vibrations. We also need to consider the actual resolution needed for these data since the aircraft will never be above roughly 150 mbar. At these pressures, the pressure broadening of transitions will be significantly higher than the maximum resolution obtainable by FIRS-2. We will also need to investigate an appropriate sampling rate to maximize the s/n of retrievals.

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